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UNIVERSITY OF ILLINOIS BULLETIN

Vol. V. AUGUST, 17, 1908 No. 39b

[Entered February 14, 1902, at Urbana, Illinois, as second-class matter under Act of Congress of July 16th, 1894.

BULLETIN No. 8. DEPARTMENT OF CERAMICS

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A Study of the Heat Distribution in Four Industrial Kilns.

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1907-1908

PUBLISHED FORTNIGHTLY BY THE UNIVERSITY

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A STUDY OF THE HEAT DISTRIBUTION IN FOUR INDUSTRIAL KILNS.

BY

A. V. BLEININGER, Champaign, Illinois.

There is a decided lack of data in regard to the consumption of fuel in periodic ceramic kilns, expressed in accurate terms, as well as with respect to the way in which the heat is distributed. It was hence thought advisable to undertake the examination of several kilns for the purpose of determining the ratio between the heat made useful and that escaping as waste. The kilns studied represented several types and widely differing conditions, one of them being a sewer pipe, one a paving brick, and two, terra cotta muffle kilns, entirely unlike in construction. In addition a building brick kiln was examined, which has already been reported upon elsewhere.*

In making a heat balance of a kilns we must determine the following factors:

A. Heat introduced as fuel.

B. Heat lost by the waste gases.

C. Heat lost by the unburnt fuel in the ashes.

D. Heat used in the burning of the ware.

E. Heat taken up by the kiln and lost by radiation.

The last factor, important though it is, cannot be estimated by any direct means available, since the difficulties opposed to its determination are too great. We must be satisfied to obtain it by difference. For, since the first four items are readily obtainable by measurement, the fifth is arrived at by the evident relation:

$$E = A - (B + C + D).$$

*"The Balance Sheet of a Down Draft Kiln," *Clay Worker*, February, 1908. Read before the N. B. M. A.

A. The heat introduced as fuel was of course readily calculated from the weight of the coal used from day to day. The calorific value of the latter was obtained by determining the heating value of a well averaged sample of the fuel in the calorimeter. This work was done in the department of industrial chemistry at the University of Illinois, under the direction of Professor Parr. The weight of the coal multiplied by its heating value gave the total number of calories introduced.

B. The heat carried out by the waste gases was calculated from the daily coal consumption, the ultimate analysis of the coal, the analysis of the stack gases, the thermal capacity of the gases and the flue temperature. The first factor was, of course, easily determined by weighing the coal, the second by the ultimate analysis of the coal, this work having been carried out in the department of chemistry under Professor Parr, the third by the analysis of the flue gases, using the Orsat apparatus, the fourth from known data, and the fifth by means of the Le Chatelier thermocouple applied in the flue as close to the kiln as possible.

The daily coal consumption permitted of calculating the weight of coal fired per hour for a certain period, which was, for the sake of convenience, taken as twelve hours. This period was considered the unit in all the calculations.

From the ultimate analysis, allowing for the carbon escaping with the ashes, the weight of the gases evolved with theoretical air supply was calculated. If, for instance, the coal had the following composition:

Carbon	60.15%—3.03 (lost in ashes)=57.12%
Hydrogen	4.15%
Oxygen	9.37%
Sulphur	4.34%—1.30 (lost in ashes)= 3.04%
Moisture	7.90%
Ash	14.09%

1 kg. of coal would result, on burning with just the requisite amount of air, in

$$0.5712 \cdot \tfrac{44}{12} = 2.09 \text{ kg of carbon dioxide}$$
$$0.0415 \cdot 9 + 0.079 = 0.453 \text{ kg. of steam}$$
$$0.0304 \times 2 = 0.060 \text{ kg. of sulphur oxide}$$
$$0.5712 \cdot \tfrac{32}{12} \times 3.35 = 5.900 \text{ kg. of nitrogen}$$

The weight of air required for the combustion of 1 kg. of this coal would then be 7.66 kg.

The flue gas analysis was simply made for the purpose of determining the amount of excess air introduced into the kiln, as this evidently changes the weight of the gases resulting from 1 kg. of the coal materially. It was endeavored to take samples from the flue so that they represented average conditions, and from two to three analyses were made each hour. This meant the making of hundreds of analyses during each burn. As the basis of the calculation of the excess air present the oxygen found was used according to the relation:

$$\text{Coefficient of air-admission} = \frac{100}{100 - 4.76 \times \%\ \text{Oxygen.}}$$

To illustrate: Supposing the gas was found to contain 5% of oxygen. We would have then:

$$\frac{100}{100 - 4.76 \times 5} = 1.31, \text{ representing total air admitted.}$$

The excess air must then be 1.31—1=0.31.

Applying this to the weights of the gases obtained above we would have:

$$\begin{aligned} 2.090 &\text{ kg. } CO_2 \\ 0.453 &\text{ kg. } H_2O \\ 0.060 &\text{ kg. } SO_2 \\ 5.900 &\text{ kg. } N_2 \\ 7.66 \cdot 0.31 = 2.370 &\text{ kg. Air} \end{aligned}$$

It might be added that the gas samples were taken as close to the kiln as possible, so as to avoid the dilution caused by the leakage of air into the flue near the damper.

In calculating the heat lost by the waste gases during any given period we must first obtain the ratio of the heat

carried out by the gases evolved from 1 kg. of coal at the flue temperature to the heating value of this weight of coal.

In this calculation there are necessary the weight of waste gases, their thermal capacity and the flue temperature.

The specific heats of the gases, as taken from the standard tables are not suitable for these calculations, since they apply only to a temperature range between 0° and 100°C, and if used would cause a more or less grave error. The work of Le Chatelier and Mallard* has clearly shown that the thermal capacity of gases is expressed by a parabolic formula of two parameters:

$$Qu = a\frac{T}{1000} + b\frac{T^2}{1000^2}$$

in which Qu=heat capacity.

a=a constant comon to all gases=6.5.

T=absolute temperature.

b=a constant, variable for different gases.

The value of b for perfect gases like O_2, N_2, H_2 and CO is 0.6, for H_2O 2.9, and for CO_2 3.7. This formula applies only to the molecular volume of each gas at absolute temperatures. For the sake of convenience it is preferable to calculate the values in terms of one kg. and the temperature in degrees C. This has been done in the following table:†

THERMAL CAPACITY OF 1 KG. GAS, IN KG. CALS.

Temperature in degrees C.	Oxygen	Nitrogen, Carbon Monoxide	Steam	Carbon Dioxide
0	0.0	0.0	0.0	0.0
200	47.3	50.0	100.0	43.1
400	88.0	100.0	203.0	91.0
600	134.0	154.0	326.0	145.0
800	181.0	207.0	461.0	208.0
1000	232.0	264.0	609.0	277.0
1200	284.0	325.0	770.0	354.0
1400	334.0	383.0	943.0	435.0

*Industrial Furnaces and Methods of Control. Emilio Damour, p. 11. Metallurgical Calculations. J. W. Richards.

†Industrial Furnaces and Methods of Control. Emilio Damour, p. 13.

By plotting a curve from these data for each gas the heat capacity of 1 kg. of the gas can be read off at once for any temperature. This was done in the work under discussion. For the purpose of illustration let us take the figures obtained above for the weights of the gases, and assuming that the gases left the kiln ot 620°C we would have the following heat capacities, the atmospheric temperature being 20°.

$$
\begin{array}{rl}
2.09 \times 145 & = 303.05 \text{ kg. cals., heat capacity of } CO_2 \\
0.453 \times 326 & = 147.68 \text{ kg. cals., heat capacity of } H_2O \\
0.453 \times 80 + 0.453 \times 537 & = 279.50 \text{ kg. cals., heat of vaporization of } H_2O \\
5.9 \times 154 & = 908.00 \text{ kg. cals., heat capacity of } N_2 \\
2.37 \times 149.4 & = 354.08 \text{ kg. cals., heat capacity of air} \\
\hline
 & 1992.31 = \text{total heat carried out by waste gases.}
\end{array}
$$

If the calorific power of the coal used is 6200, it is evident that the heat lost by the waste gases must be equal to $\frac{1992}{6200} \times 100 = 32.13$ per cent. For every 100 pounds of coal fired we thus lose in the waste gases 32.13 pounds.

The temperature, as has already been stated, was obtained by means of the Le Chatelier thermocouple, inserted into the flue close to the kiln. Corrections were made for the atmospheric temperature. This was done by fastening a thermometer to the junction between the platinum and the copper wire. The correction is equal to 0.5 of the thermometer reading where the atmospheric temperature does not exceed 40°. In very hot places the correct procedure is to insert the copper junction in boiling water and to calibrate the couple under these conditions. The calibration is to be made by means of the melting points of zinc, silver and gold or copper.

In the losses due to the waste gases must be included also the loss due to the escape of combustible gases. Under the conditions of the kilns examined in this work the amount of carbon monoxide found in the gases was very small. Immediately after firing some of this gas was found, but it disappeared in a few minutes. For this rea-

son it was not included in the losses incurred by the flue gases. It seems that the hot mass of clay tends to promote the oxidation of the combustible gases formed in the furnace.

D. The heat required to raise the ware to the ultimate temperature of the kiln was calculated from the weight of the ware, its specific heat and the kiln temperature. The amount of water contained in the clay was taken into consideration. Unfortunately, several important constants are lacking, such as the heat of dehydration of clay and the heat of vaporization of the hygroscopic water. Even the specific heat of clay is not known for the higher temperatures, though it is usually given in text books as being 0.2. Mr. J. K. Moore, during some recent work in connection with his thesis, found the average thermal capacity of a burnt No. 2 fire clay between the limits of 400-1100°C to be 0.235. At the time the calculations for this work were made the specific heat of clay was taken as 0.2. The heat of dehydration was assumed to be 200 gr. calories per gram of water. No reliable data was obtainable on this subject. The latent heat of the hygroscopic water which leaves in the neighborhood of 200° was taken to be 476 according to the formula of Griffith's,

$$L=596.73-0.60t.$$

Assuming then a clay, containing 2% of hygroscopic and 7% of chemical water which is to be raised to 1120°, we would have for 1 kg. of the dried clay the following heat consumption, the atmospheric temperature being 20°. The dehydration temperature to be taken as 650°.

Hygroscopic water	$0.02\times180\times1=$	3.6 kg. calories
	$0.02\times476 =$	9.5 kg. calories
Chemical water	$0.07\times.02\times650=$	9.1 kg. calories
	$0.07\times200 =$	14.0 kg. calories
Clay	$0.93\times0.2\times1100=$	204.6 kg. calories
1 kg. clay thus requires		240.8 kg. calories

E. As has been mentioned above, the heat absorbed by the kiln and lost by radiation was obtained by difference.

APPARATUS.

The apparatus used in this work consisted of the Orsat gas apparatus, two tin gas samplers, supported by tripods and painted with asphaltum paint, one Siemens-Halske milli-voltmeter and double throw switch, two thermocouples, one for the flue, the other for the kiln, two thermometers reading to 100°C and two to 300°, the latter being used during the watersmoking period, and two Richardson-Lovejoy metal draft gauges, filled with colored petroleum and showing a reading magnified four times.

The gas was drawn from the flue through ¾″ pipes plugged at the end and perforated around the side. The pipe connected to the draft gauge was provided with an elbow so that the end of the pipe was parallel to the axis of the flue and pointed in the direction of the stack. This was found to be important, giving more consistent readings than when the pipe was inserted at right angles to the flue.

DRAFT GAUGE.

The readings of the draft gauge were not necessary for the determination of the heat escaping through the stack, since the weight of coal actually fired was used as the basis of the calculations, but they were useful in indicating the increasing velocity of the gases in the stack. The draft gauge without a Pitot tube cannot be used to measure the velocity of the gases except it is calibrated against an anemometer. A Pitot tube suitable for the purpose was not available, since the usual metal instrument would soon be destroyed by the high temperature of the gases and the time was too short for making a clay tube of this kind.

With the Pitot tube the velocity of the gases in the flue or stack is calculated from the relation.

$$V = \sqrt{2\,gh\,\frac{d_1}{d_2}}$$

where v=the velocity in feet or meters per second.

g=the gravity constant, 32.14 ft. or 9.8 meters.

h=*real* height of the petroleum column in feet or meters, shown by the draft gauge.

d=density of petroleum, in terms of water at 4°C.

d=density of the gases at the temperature and pressure of the stack or flue in terms of water at 4°.

The relation between the real velocity as determined by the anemometer and that calculated from the Pitot tube is approximately 1.1—1.2, for the velocities in question in ceramic stacks. The Pitot tube velocities are hence to be multiplied by this factor in order to obtain the real velocity.*

Some erroneous conceptions are current in regard to the meaning of the draft gauge readings. The value indicated by the gauge does not represent the total magnitude or "head" of the draft, but only that part of it which corresponds to the velocity of the gases and which is not available for pulling the gases through the furnaces and kiln.

The total head of draft which may be expressed in inches or millimeters of water or air at 0° is the pull obtained by a stack, measured by the difference in the weight of the hot gases occupying the chimney and the weight of the same volume of air at atmospheric temperature. To illustrate, assuming a stack 10 meters high and 1 square meter in cross section at 273°C, with the atmospheric air at 0°, we have a difference in weight as follows: The weight of 10 cubic meters of air (volume of stack) at 0°C= 12.93 kg. The weight of the same volume of air at 273°= 6.465 kg. We have, then, as the measure of the total draft the weight of 12.93−6.465=6.465 kg. This weight is distributed over the cross section of 1 sq. meter=10000 sq. cm. The pressure upon 1 sq. cm. is thus 0.65 gram. This corresponds to a height of a water column of 0.65 cm. Expressed in terms of air at 0° it is 0.65×772=501.8 cm., water being 772 times as heavy as air at the same tempera-

*W. D. Harkins and R. E. Swain. Jour. Am. Chem. Soc., Vol. 29, p. 970.

ture. This head of 5.02 meters represents the total draft. But only part of it is available for forcing the air needed for combustion into the furnaces and pulling out of the kiln the gases produced. Part of this force is taken up by the velocity of the stack gases and part of it by the friction of the gases in the stack. The head available for the kiln, then, is equal to the total head minus the velocity and friction heads.

The velocity head is calculated from the relation

$$h_1 = \frac{V^2}{2g}.$$

Assuming the velocity of the gases in the above stack to be 6 meters per second, the velocity head, h_1, becomes

$$h_1 = \frac{36}{2 \times 9.8} = 1.84 \text{ m., in terms of air at } 273°.$$

Reduced to terms of air at 0° this head becomes 0.92m. According to Richards the friction head, h_2, of a stack is:

$$h_2 = 1.9 - K\frac{H}{d}$$

where H=height of stack.

d=diameter or side of chimney.

k=constant, whose average value=0.08.

Substituting, we obtain

$$h_2 = 1.9 - \frac{10}{1}.0.08 = 0.15 \text{ meters.}$$

The head of the stack thus available for pulling the gases through the kiln=5.02 − (1.84+0.15)=3.03 meters of air at 0°.

Experimentally, the total head of a stack may be determined by suddenly dropping the damper and observing the draft gauge reading instantly. The common idea that the draft of a kiln is increased greatly as the stack becomes very hot is not true. It is true that the draft in-

creases up to a certain temperature but not beyond it, in spite of the fact that the velocity of the gases increases. But as we have seen, increased stack velocity means increased loss in available head. It must be remembered that the draft of a stack is not measured by the volume of the gases drawn off, but by the *weight* of gas removed per unit time.

We have thus the expression:

$$Qu = \frac{Sd\sqrt{2g\,0.00366.L\ (t_1 - t_2)}}{1 + 0.00366\,t_1} \quad \text{where}$$

Qu = the weight of the gases removed per second.
S = cross section of stack.
d = density of the gases at 0°.
g = 9.8 m. or 32.14 feet.
L = height of stack.
t_1 = mean temperature of the gases in the stack in degrees C.
t = temperature of the air in degrees C.

Since here $Sd\sqrt{2\,g\,0.00366\,L}$ = constant we may say that

$$Qu = K\,\frac{\sqrt{t_1 - t}}{1 + 0.00366\,t_1}$$

By differentiation or graphical determination of the maximum value of Qu we find that the temperature at which the greatest weight of gases is removed is at 273°C. Nothing is gained, therefore, as far as the *available* draft of a stack is concerned, by maintaining a mean stack temperature higher than 273° above the atmospheric temperature.

SEWER PIPE KILN.

The kiln in question was one of the older kilns on the plant and was rectangular, its dimensions being: Length, 42 feet, width, 17½ feet, height, 19 feet, inside measurements. It was set with double strength 20 inch pipe, nested with smaller sizes, and contained 120,460 pounds of clay, all told, including rings, etc.

In burning, 87,335 pounds of coal were used, which had the following composition:

Carbon	59.76%
Hydrogen	4.08%
Oxygen and Nitrogen	10.72%
Sulphur	2.57%
Ash	11.74%
Moisture	11.13%

The ash was found to show the following analysis:

Carbon	29.17%
Hydrogen	0.26%
Oxygen and Nitrogen	3.13%
Sulphur	3.16%
Ash	68.99%
Moisture	1.55%

The calorific power of the coal was 6,020 calories, or 10,837 B. T. U.

The weights of the gases from 1 kg. of coal were:

$$CO_2 = 2.070 \text{ kg.}$$
$$H_2O = 0.478 \text{ kg.}$$
$$N_2 = 5.765 \text{ kg.}$$

assuming perfect combustion. The weight of air required per kg. of coal is 7.48 kg.; 3.42 per cent of carbon were lost in the ashes.

The length of the burn was 129 hours. This was divided into 10 periods of 12 hours and one of 9 hours. All the analyses and other data were averaged on the basis of the 12 hour period, care having been taken to make the analyses representative of the average conditions.

In Fig. 1 we have represented the average coal consumption per hour during the burn. Fig. 2 shows the time-temperature curves of the kiln and flue. In Fig. 3 there are shown the average carbon dioxide and air percentages for each period throughout the burn.

HEAT LOST BY WASTE GASES.

In calculating the heat passing off with the waste gases from the data represented by the above curves, the *mean* flue temperature from the beginning to the end of each period was taken and the atmospheric temperature

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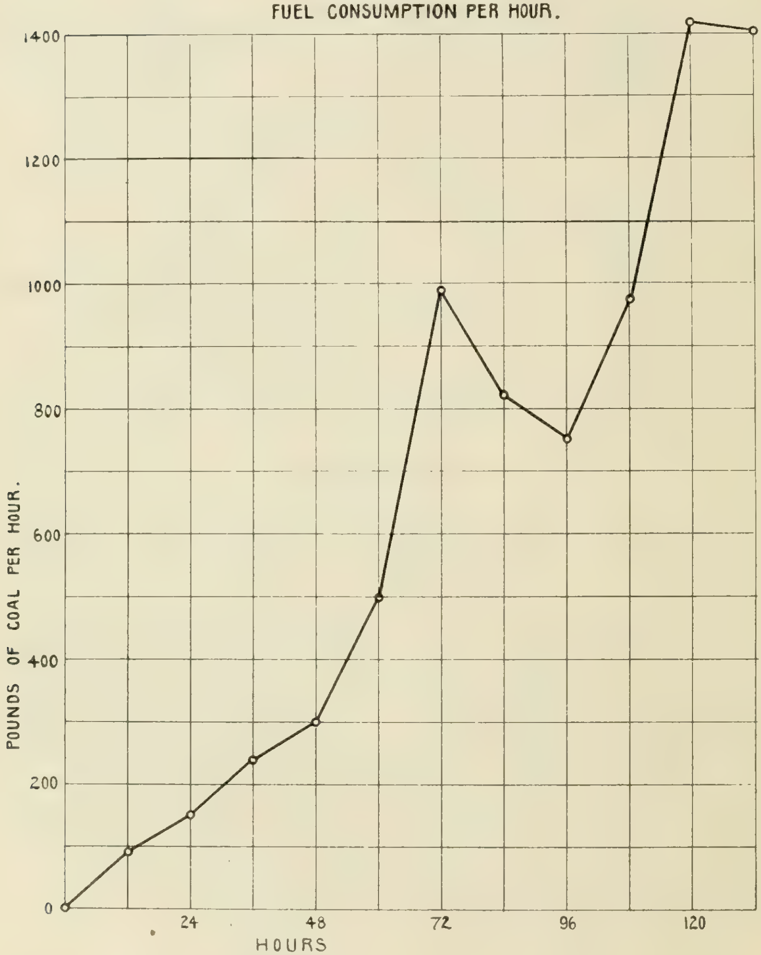
FIG 1.
SEWER PIPE KILN.
FUEL CONSUMPTION PER HOUR.



deducted. The heat carried out by the gases corresponding to 1 kg. of coal was then calculated, as shown in the first part of this paper. In the case of the sewer-pipe kiln the waste heat of each period is given in the following table:

Period	1	2	3	4	5	6	7	8	9	10	11
Kg. calories lost per kg. of coal	312	373	711	611	539	522	673	1250	1610	1450	1726
% lost in terms of heating value of coal	5.18	6.20	11.81	10.15	8.96	8.67	11.18	20.78	26.74	24.09	2867
Pounds of coal lost by waste gases per period	52.2	111.2	331	364	542	1030	1141	1886	3148	4131	3615

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FIG 2.
SEWER PIPE KILN.
TIME-TEMPERATURE CURVE.

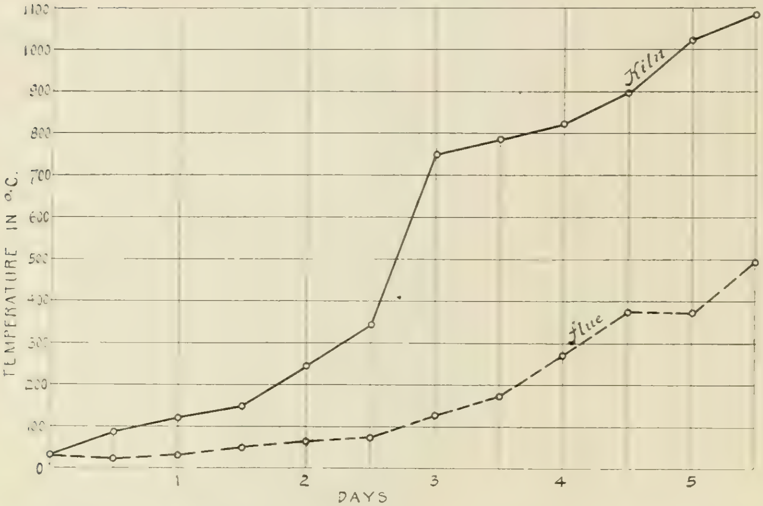

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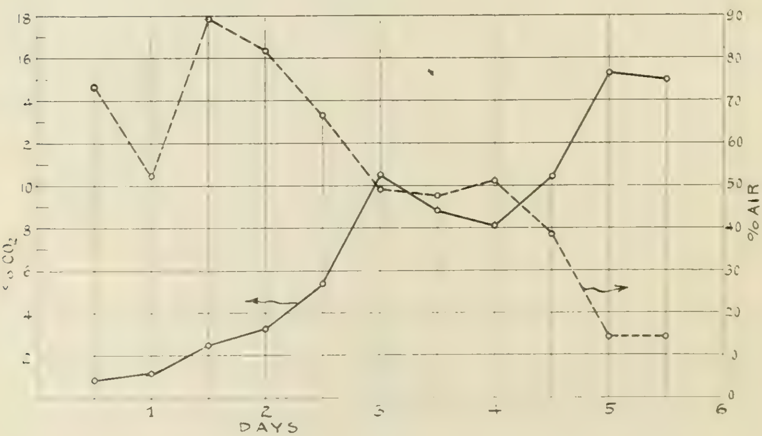
FIG 3.
SEWER PIPE KILN.
AVERAGE CARBON DIOXIDE
&
AIR CONTENT OF FIRE GASES.



Adding up the pounds of coal which express the loss of heat by the waste gases we obtain 16351 pounds. Since the total coal fired was 87,330 pounds, it is evident that the heat escaping through the flue is equal to 18.6 per cent. Fig. 4 shows the losses for each period of the burn.

HEAT REQUIRED TO BURN THE WARE.

Calculating the heat required to burn 120,460 pounds of clay, as illustrated above, to a temperature of 1100° there will be used 13,689,179 kg. calories, which equal 4987 pounds of the coal employed in this case. This corresponds to 5.71% of the total heat introduced into the kiln.

HEAT LOST IN THE ASHES.

The carbon lost in the ashes amounts to 3.42% of the coal. Since practically no available hydrogen was found

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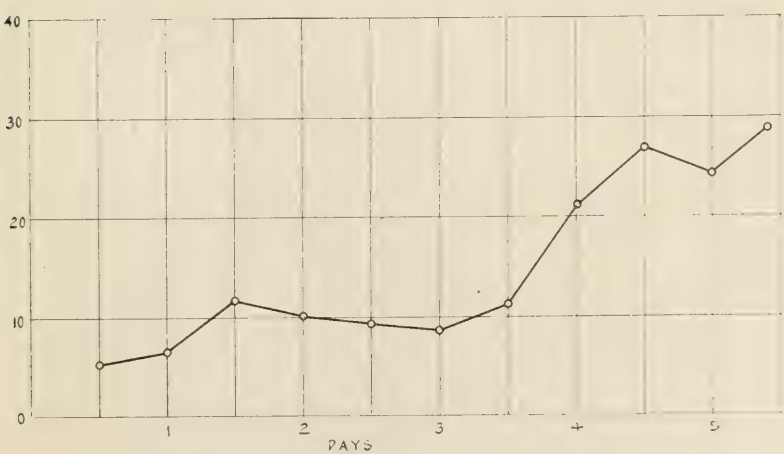
FIG 4.
SEWER PIPE KILN.
%HEAT LOST BY WASTE
GASES IN TERMS OF HEAT INTRODUCED.



in the ashes, the heat lost in this way evidently is 0.0342× 8080 kg. calories per kg. of coal. Calculating this loss in percentage we obtain 4.58%.

HEAT TAKEN UP BY THE KILN AND LOST BY RADIATION.

The heat coming under this heading is evidently obtained by subtracting the sum of 18.6%+5.71%+4.58% from 100 which gives us 71.1%, a very high percentage, approaching the similar losses of open-hearth steel furnaces and must be ascribed to the poor condition of the kiln.

In Fig. 5 the draft-gauge readings are plotted, expressed in draft gauge divisions and inches. The gauge was frequently set to the zero point to allow for the evaporation of the petroleum.

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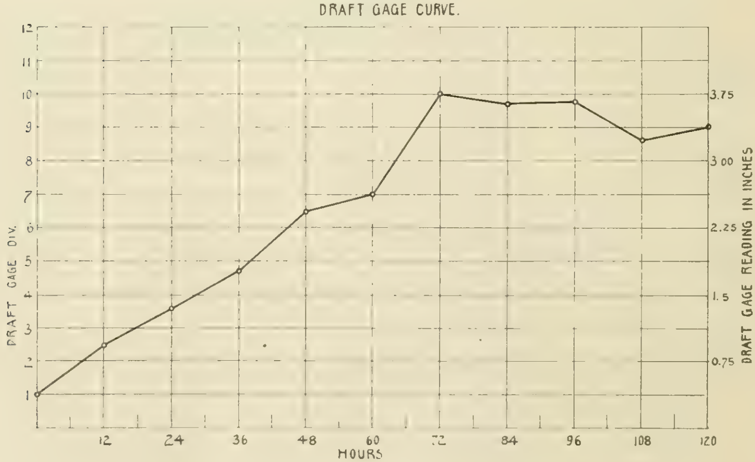
FIG 5.
SEWER PIPE KILN.
DRAFT GAGE CURVE.



Collecting the data obtained in these calculations we find the heat distribution to be as follows:

Heat lost by the fire gases	18.6 %
Heat taken up by the ware	5.7 %
Heat lost by ashes	4.58%
Heat taken by kiln and lost by radiation	71.1 %
	100.0%

In burning 1000 kg. of ware there were used 4378341 kg. cals.
In burning 1 ton of ware there were used 3984200 kg. cals.
In burning 1 ton of ware there were used 1456.8 lbs. of coal
Temperature 1100°C.

During salting the fire gases were found to contain 15.6% CO_2 and 2.4% O_2. An interesting fact observed was also that the temperature during salting rose 5° in spite of the fact that the reactions involved in salting are endothermic, thus showing that there is no difficulty in maintaining sufficient heat.

During the latter part of the burn some carbon monoxide was found in the gases, but only for a short time and in small amounts. The loss of heat due to this source was hence neglected.

PAVING BRICK KILN.

This kiln was a 26 ft. round down draft kiln and contained 357,264 pounds of burnt clay. The amount of coal used was 121,928 pounds. The maximum temperature reached was 1110°C.

Analysis of coal:

Carbon	60.15%
Hydrogen	4.15%
Sulphur	4.34%
Oxygen and Nitrogen	9.37%
Ash	14.09%
Moisture	7.90%

The calorific power was found to be 6231 or 11216 B. T. U.

Analysis of ashes:

Carbon	21.53%
Hydrogen	0.11%
Sulphur	1.81%
Oxygen and Nitrogen	0.83%
Ash	77.30%
Moisture	0.08%

Thus 3.03% of carbon in the coal was lost with the ashes.

From 1 kg. of this coal there would be evolved:

2.090 kg. carbon dioxide
0.453 kg. steam
5.900 kg. nitrogen

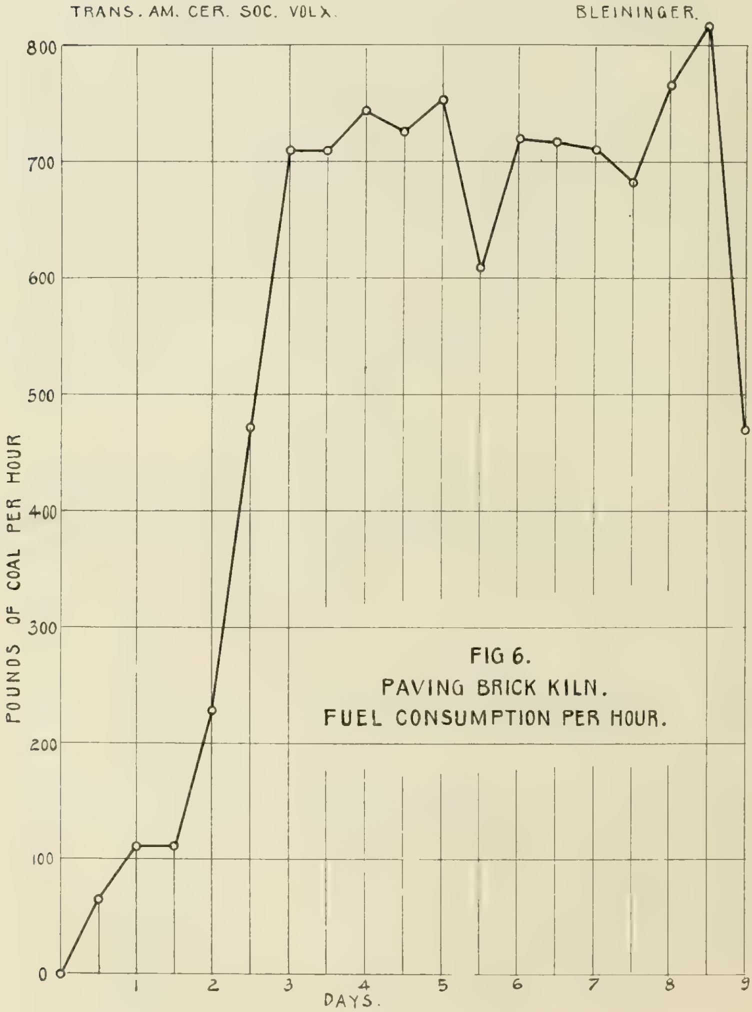
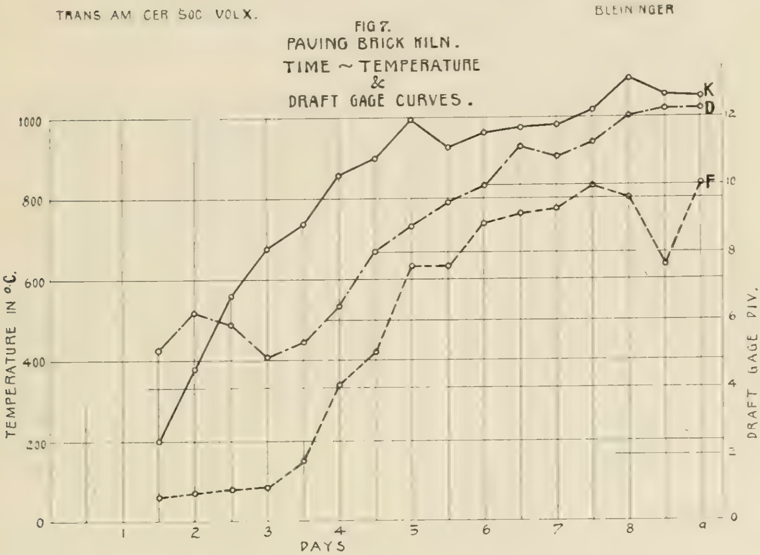


FIG 6.
PAVING BRICK KILN.
FUEL CONSUMPTION PER HOUR.



not considering the sulphur dioxide and assuming perfect conditions of combustion. For each kg. of coal fired there would have to be introduced 7.66 kg. of air for theoretical combustion.

The length of the burn was 204 hours.

The coal consumption per hour is shown in Fig. 6 for each period of 12 hours throughout the burn. Fig. 7 gives the time-temperature curves for the kiln (couple introduced on top) and the flue as well as the draft gauge readings. The latter are taken from the stack, and it must be remembered that each division equals $\frac{3}{4}$ inch and that the readings are magnified four times. Each division thus corresponds to 3-16 inch of petroleum, vertical height. In Fig. 8 the CO_2 and air contents of the gases are represented. From the air curve we observe that the shale is not a difficult one to oxidize, that the air content of the gases is not excessive, and the heat losses are not so much due to large air excess as to the high exit temperature of the waste gases.

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FIG 8.
PAVING - BRICK KILN.
AVERAGE CARBON DIOXIDE
&
AIR CONTENT OF FIRE GASES.

HEAT CARRIED OUT BY WASTE GASES.

Proceeding as before we can calculate the heat carried out into the flue from the weight of coal fired per period, the air content of the gases and the flue temperature, so that we have the following results:

Period	1	2	3	4	5	6	7	8	9
Kg. calories lost per kg. of coal	1237	1428	797	698	564	466	719	938	1408
% of heat lost in terms of heating value of coal	19.85	22.92	12.8	11.21	9.05	7.48	11.54	14.7	22.60
Pounds of coal lost by waste gases per period	156	305	171	307	518	645	995	1355	2001

Period	10	11	12	13	14	15	16	17	18
Kg. calories lost per kg. of coal	1847	2685	2390	2875	2561	3005	2653	2400	3839
% of heat lost in terms of heating value of coal	29.63	43.09	38.36	46.14	41.10	48.20	42.58	38.53	61.61
Pounds of coal lost by waste gases per period	2693	3174	3366	4122	3516	2472	3970	3804	2884

Adding the pounds of coal, which are equal to the heat wasted by the fire gases, we obtain 36,454 pounds, which is 29.9% of the total amount of coal fired, or we may say that the kiln shows a flue loss of 29.9%. Fig. 9 shows the heat loss per period graphically.

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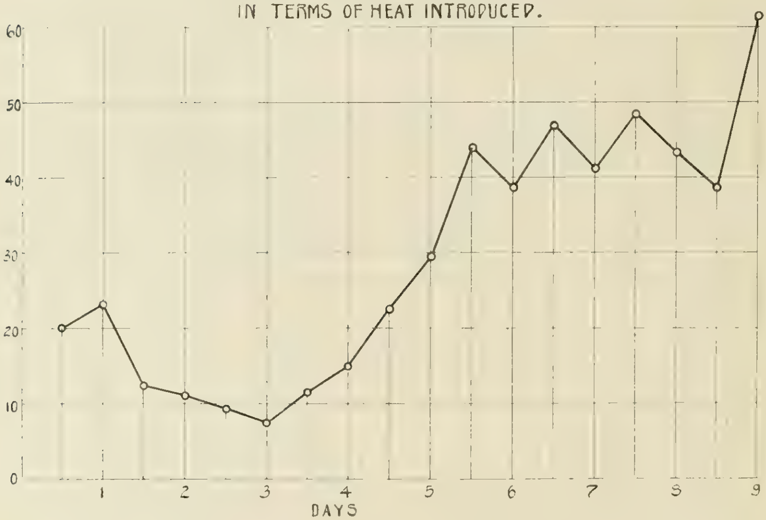
FIG 9.

PAVING-BRICK KILN.
% HEAT LOST BY WASTE GASES PER PERIOD
IN TERMS OF HEAT INTRODUCED.



HEAT REQUIRED IN HEATING UP THE WARE.

Calculating the amount of heat theoretically necessary to raise the clays to 1110°C, as shown above, we find that this heat is equal to 13,778 pounds of coal, which is 11.3% of the total amount.

HEAT LOST BY UNBURNT CARBON IN THE ASHES.

Since the carbon lost by the ashes is equal to 3.03% of the coal, the heat lost in this way must be equal to $8080 \times 0.0303 = 245$ calories, or 3.9% of the calorific value of the coal.

HEAT TAKEN UP BY THE KILN AND LOST BY RADIATION.

This necessarily must be equal to 100−45.1=54.9%. Summarizing, we have the following heat distribution:

Heat lost by the waste gases	29.9%
Heat taken up by the brick	11.3%
Heat lost by carbon in the ash	3.9%
Heat taken up by the kiln and lost by radiation	54.9%
	100.0%

In this kiln and under the conditions of the test carried on

1000 kg. burnt clay required 2056230 kg. calories.
1 ton burnt clay required 1871169 kg. calories.
1 ton burnt clay required 660 pounds of coal.
Temperature 1110°C.

TERRA COTTA KILN. A.

This kiln was a muffle kiln, the muffle being 16 ft. in diameter. The kiln was set with 42,423 pounds of green terra cotta and 26,960 pounds of supports, kiln blocks, etc. The coal consumed was 29,340 pounds, and the duration of the burn was 67 hours. The maximum temperature reached in the muffle was 1080°C.

Coal analysis:

Carbon	66.78%
Hydrogen	4.81%
Sulphur	0.84%
Oxygen and Nitrogen	9.68%
Ash	7.59%
Moisture	10.30%

Calorific power 6716 or 12090 B. T. U.

Analysis of ashes:

Carbon	20.92%
Hydrogen	0.06%
Sulphur	0.35%
Oxygen and Nitrogen	0.53%
Ash	77.94%
Moisture	0.20%

Assuming theoretical combustion, the weight of the gases developed from 1 kg. of coal is 2.39 kg., carbon diox-

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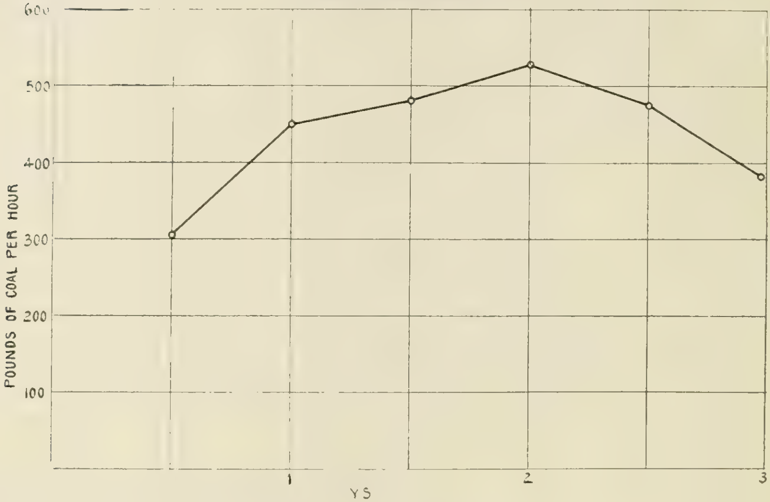
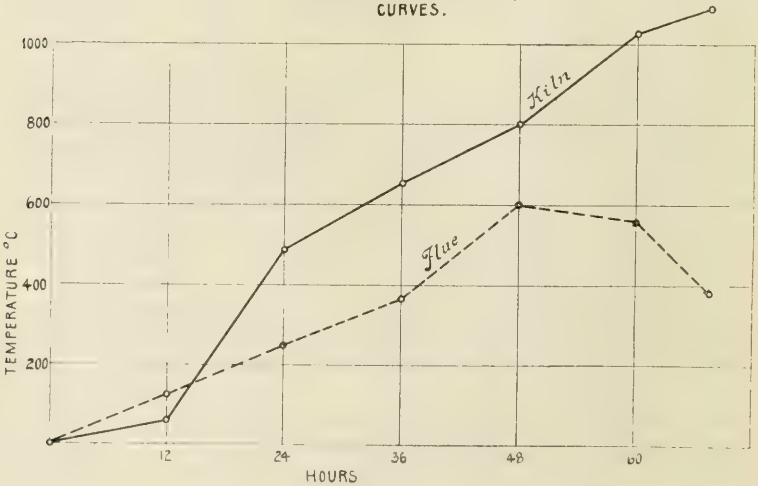
FIG 10.
TERRA COTTA KILN A.
COAL CONSUMPTION PER HOUR.



TRANS AM CER SOC VOL X BLEININGER

FIG 11.
TERRA COTTA KILN A.
TIME ~ TEMPERATURE,
CURVES.



ide, 0.553 kg. steam, and 5.8 kg. nitrogen, the sulphur being neglected. The air introduced under the same conditions would be 7.54 kg.

Fig. 10 shows the average coal consumption per hour for each period of 12 hours. It is seen to differ from the corresponding curve for the open kilns by the comparatively small fluctuations in the amounts of fuel fired, as is to be expected from this type of kiln. The time-temperature curve is given in Fig. 11. The CO_2 and air curves of

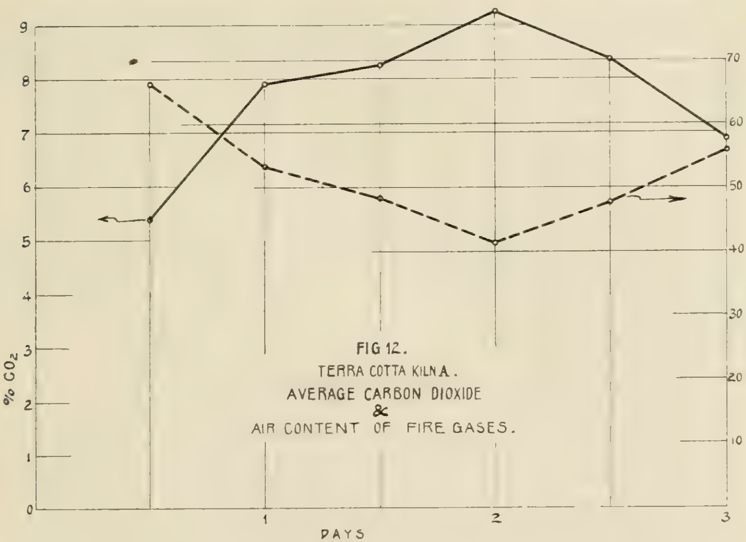


Fig. 12 indicate strongly oxidizing conditions throughout the burn. The draft gauge readings have been rejected owing to the rather unsatisfactory place at which the gauge was connected to the flues surrounding the muffle.

HEAT CARRIED OUT BY THE WASTE GASES.

Proceeding with the calculation of the flue loss we can tabulate the results as follows:

Period	1	2	3	4	5	6
Kg. calories lost per kg. of coal	741	1102	1476	1954	2622	2510
% of heat lost in terms of heating value of coal	11.0	16.4	22.0	29.1	39.0	37.4
Pounds of coal lost by waste gases per period	396	876	1248	1830	2214	1017

Adding up the amounts of coal we have 7581 pounds. which is 25.8% of the total amount of fuel used, 29,340 pounds. In Fig. 13 the average heat losses per period are shown graphically.

HEAT REQUIRED TO BURN THE WARE.

Calculating the heat theoretically required to burn the terra cotta and to heat up the supports, we find that this amounts to 3,688 pounds, or 12.57% of the total heat introduced.

HEAT LOST BY CARBON IN THE ASHES.

The carbon lost with the ashes amounts to 1.6% of the coal. Thus the heat lost in this way is $(8080\times0.016)\div 6716\times100=1.9\%$. In this kiln the grates were in excellent shape, and this explains the low loss.

HEAT TAKEN UP BY THE KILN AND LOST BY RADIATION.

It is evident, then, that the loss must be equal to $100-(25.8+12.57+1.9)=59.73\%$.

Summarizing, the heat distribution is as follows:

Heat lost by waste gases	25.80%
Theoretical heat necessary to heat up charge	12.57%
Lost by carbon in the ashes	1.90%
Heat taken up by kiln and lost by radiation	59.73%
	100.00%

1000 kg. terra cotta under these conditions required 5113775 kg. cals.=1675 pounds of coal.

1000 kg. terra cotta plus supports: 3007205 kg. cals. =985 pounds of coal.

1 ton terra cotta required 1524 pounds of coal.

1 ton terra cotta plus supports 896 pounds of coal.

Temperature=1080° C.

In taking several samples of gas from the muffle during the raising of the heat, 3% of CO_2 were found.

TERRA COTTA KILN. B.

This kiln was constructed entirely differently from the preceding one. Its inside muffle diameter was 21′6″, its height 17 feet high in the center and 12 feet to the spring of the arch. The charge consisted of 113,280 pounds of terra cotta and 75,694 pounds of kiln stones and supports. The fuel used amounted to 81,420 pounds of coal. Length of burn, 115 hours. The kiln was well built and in excellent condition. The maximum temperature was 1115° C.

Analysis of coal:

Carbon	69.30%
Hydrogen	4.62%
Sulphur	1.64%
Oxygen and Nitrogen	9.94%
Ash	6.55%
Moisture	7.95%

Calorific power 6961, or 12530 B. T. U.

Analysis of ash:

Carbon	20.53%
Hydrogen	0.22%
Sulphur	0.51%
Oxygen and Nitrogen	1.03%
Ash	77.40%
Moisture	0.31%

1.34% of carbon was lost in the ashes. 1 kg. of coal resulted in 2.49 kg. carbon dioxide, 0.495 kg. of steam, and 6.97 kg. nitrogen, assuming theoretical combustion, and 1 kg. of coal required under these conditions 8.24 kg. of air for combustion.

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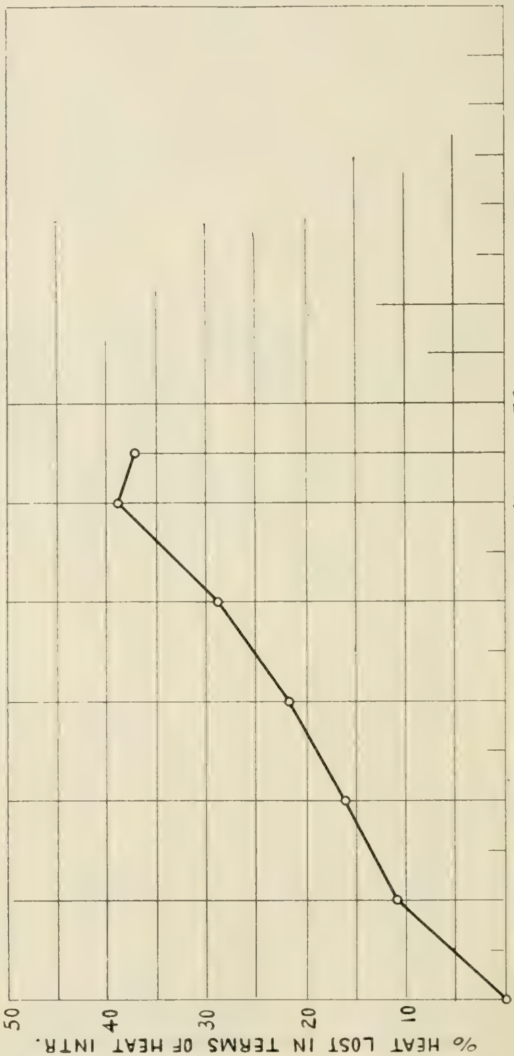
FIG 13.
TERRA COTTA KILN A.
% HEAT LOST PER PERIOD BY WASTE
GASES IN TERMS OF HEAT INTRODUCED.



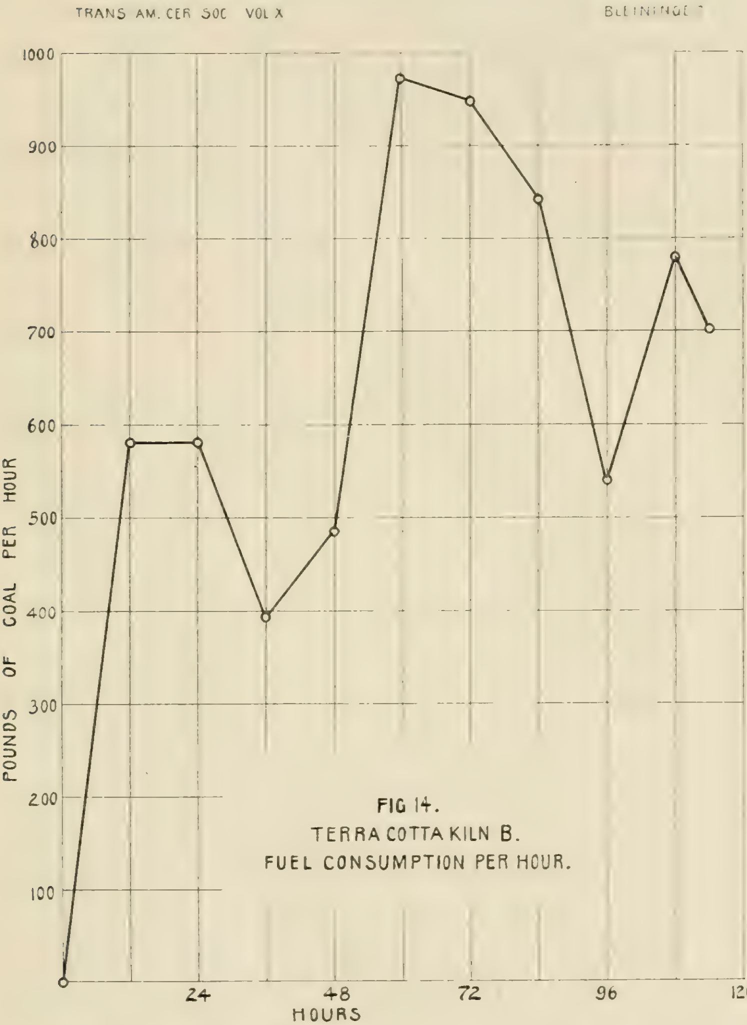


FIG 14.
TERRA COTTA KILN B.
FUEL CONSUMPTION PER HOUR.

Fig. 14 shows the coal consumption per hour as the average for each period of 12 hours. In Fig. 15 we have the time-temperature curves for the kiln and the flue as well as the draft gauge readings. It is shown here that the fire gases leave at a very high temperature and that hence a large flue loss is to be expected. The difference

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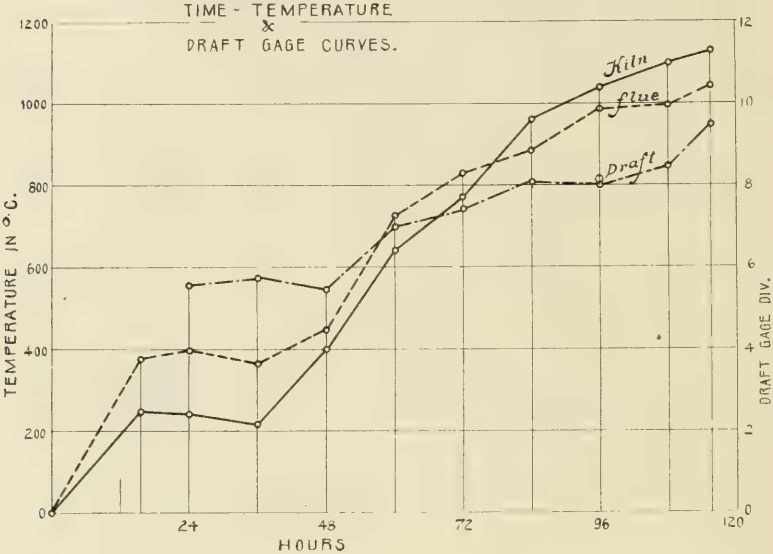
FIG 15. TERRA COTTA KILN B.
TIME - TEMPERATURE & DRAFT GAGE CURVES.



TRANS AM CER SOC VOL X. BLEININGER

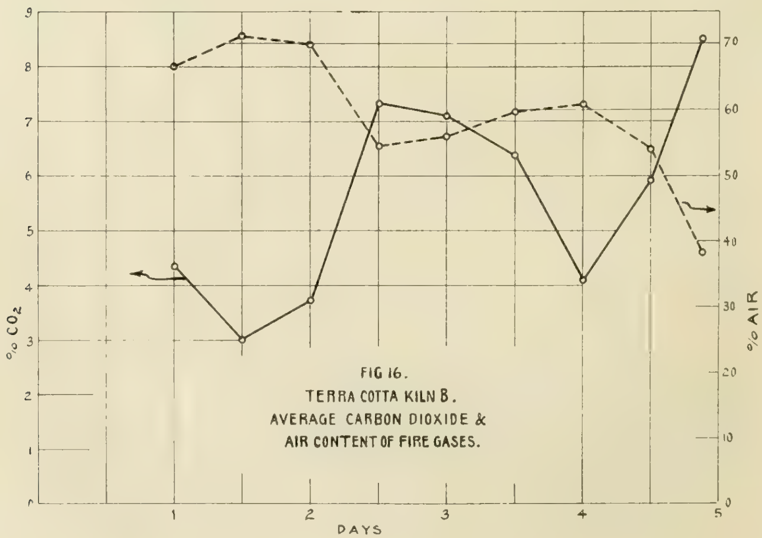


FIG 16.
TERRA COTTA KILN B.
AVERAGE CARBON DIOXIDE & AIR CONTENT OF FIRE GASES.

in construction between kilns A and B is brought out clearly by these curves. Fig. 16 illustrates the average carbon dioxide and air contents of the fire gases representing for each period. It is observed that in this kiln also the conditions are decidedly oxidizing.

HEAT LOSSES DUE TO THE FLUE GASES.

The results of the calculations are again indicated in a table, viz:

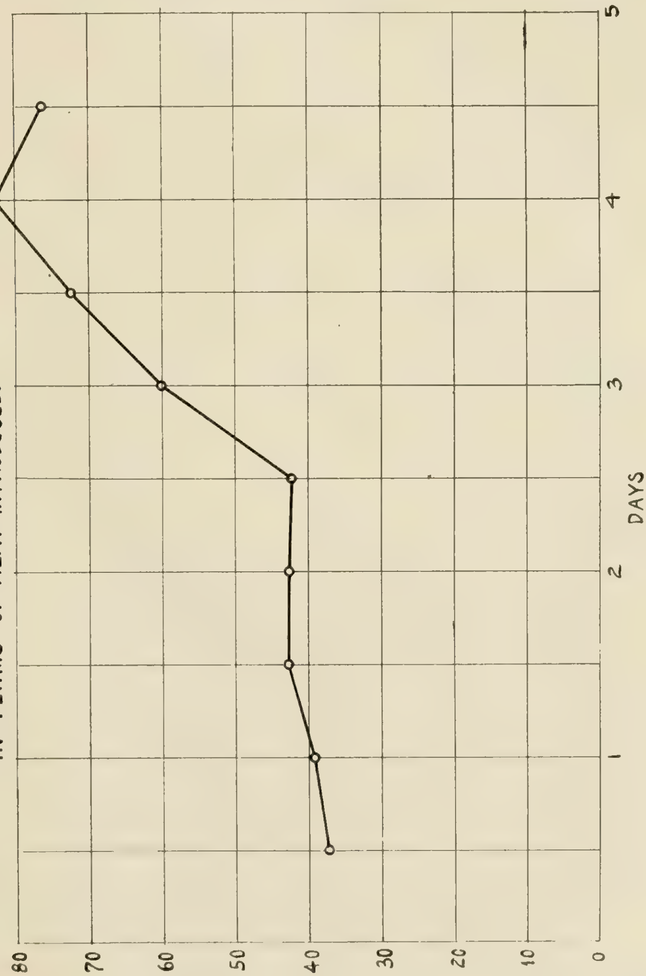


FIG 17.
TERRACOTTA KILN B.
% HEAT LOST BY WASTE GASES
IN TERMS OF HEAT INTRODUCED.

BLEININGER.

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Period	15½ hrs. 1	2	3	4	5	6	7	8	9	10
Kg. calories lost per kg. of coal	2576	2704	2992	3019	3007	4155	5031	5762	5281	4387
% of heat lost in terms of heating value of coal	37.0	38.8	43.0	43.4	43.2	59.7	72.3	82.8	75.9	63.0
Pounds of coal lost by waste gases per period	2581	2706	2044	2545	5000	6719	7335	5381	7099	5068

Fig. 17 shows the percentage of heat lost during each period.

Adding up these amounts of coal we find that the pounds of coal lost by the waste gases are equal to 46,478 pounds, or 57.1% of the total amount of coal, 81,420 pounds.

HEAT REQUIRED TO BURN THE WARE.

By calculation the theoretical amount of heat required to burn the terra cotta and heat up the supports was equal to 6514 pounds, or 8% of the total amount of coal.

HEAT LOST BY UNBURNT CARBON IN THE ASHES.

Since the carbon lost to the ashes amounts to 1.34%, the percentage heat loss due to this cause is $[(8080\times 0.0134)\div 6961]\times 100=1.6\%$.

HEAT TAKEN UP BY THE KILN AND LOST BY RADIATION.

This is equal to $100-(57.1+8.0+1.6)=33.3\%$. This item, therefore, is very small for this kiln, which speaks well for its construction.

Summarizing, we have:

Heat lost by the waste gases	57.1%
Theoretical heat required for charge	8.0%
Heat lost by unburnt carbon	1.6%
Heat lost to kiln and radiation	33.3%

1000 kg. terra cotta required 5002518 kg. calories.
1000 kg. terra cotta and supports 3072423 kg. calories.
1 ton terra cotta required 1439 pounds of coal.
1 ton terra cotta and supports 884 pounds of coal.
Temperature 1115°C.

It will be observed that in spite of the large flue loss in kiln B and the higher muffle temperature the efficiency is about the same as that of A, this being due to the larger size and hence greater tonnage of B.

For the sake of completeness the writer desires to quote the results obtained for a brick kiln,* burning hard

*The *Clay Worker*, February, 1908.

shale building and sewer brick. This kiln was of the down draft type, 28 feet inside diameter, and contained 66,190 brick, each weighing 6 1/8 pounds. The amount of coal consumed was 95,045 pounds, the B. T. U. value being 11162. The summary of the heat distribution of this kiln was as follows:

Heat lost by the flue gases	27.33%
Theoretical heat required to burn bricks	19.55%
Heat lost by unburnt carbon	3.51%
Heat taken up by kiln and lost by radiation	49.61%
	100.00%

1000 kg. of brick required 1,449,174 kg. calories, or for each ton of ware 468 pounds of coal were fired. The temperature was 1100°C.

Comment on the work of this article is hardly necessary since the figures themselves are the conclusions to be drawn. It might facilitate comparison to arrange the absolute quantities of heat required in each case.

1000 kg. sewer-pipe	4378341 kg. calories
1000 kg. paving brick	2056230 kg. calories
1000 kg. terra cotta, A	4640756 kg. calories
1000 kg. terra cotta plus supports	3007205 kg. calories
1000 kg. terra cotta, B	5002518 kg. calories
1000 kg. terra cotta plus supports	3072423 kg. calories
1000 kg. hard building brick	1449174 kg. calories

Expressing these values in pounds of coal per ton we have:

1 ton sewer pipe	1457 pounds coal
1 ton paving brick	660 pounds coal
1 ton terra cotta, A*	1524 pounds coal
1 ton terra cotta and supports	896 pounds coal
1 ton terra cotta, B	1439 pounds coal
1 ton terra cotta and supports	884 pounds coal
1 ton building brick	468 pounds coal

In conclusion the writer wishes to acknowledge his indebtedness to Professor C. W. Rolfe for having granted the use of the funds and apparatus which made the work possible. He also desires to express his appreciation of the conscientious services and faithful cooperation of Mr. C.

*The coal used in A is inferior in heating value to that in B.

E. Merry, of the department of ceramics, University of Illinois. He wishes to thank especially the firms whose kind ooperation was enjoyed in every case.

DISCUSSION.

Mr. Langenbeck: I wish to ask about the percent loss of waste gases—I presume by that the speaker means both the lost heat of the gases during the combustion of the kiln and the heat loss by radiation, not only from the outside during the burning, but also during the cooling of the ware through the stack. Did you attempt in any way taking the temperature on the outside of the kiln at the various points and times to determine what the percent of this loss was, this radiation of the kiln shell during the combustion?

Mr. Bleininger: I have made no attempt to do this since this is a very difficult matter, no reliable data being at hand to serve as the starting point of such calculations. The German Government is endeavoring to obtain the necessary facts by experimental researches. There is absolutely no reliance to be placed on any data found in handbooks concerning radiation. There are any number of theoretical calculations on this subject, but they do not agree in their deductions.

Mr. Langenbeck: I am glad the German Government is investigating this, for it is a matter of vital importance. Firing a kiln is piling up heat in its shell, and we usually think only that the inflow must be greater than the outflow. At the same time a large and increasing amount of heat is being radiated on the outside; and while, relatively, fire brick work is a poorly conducting substance, yet it is by no means as poor as it ought to be; and this is one of the gross defects of our kilns. We simply go on building kilns of fire brick instead of more effective insulating material, instead of using hollow brick. The saving, entirely, aside from the possible saving in fuel, is in the steadier accumulation of heat in the kiln by a lessened radiation from the

outside. The only larger practical work I have attempted along this line was in building a kiln at the Mosiac Tile Co., in Zanesville, Ohio, where I left an air space between the fire brick lining and red brick outside, and I held the fire brick lining in place by a header brick which extended an inch or an inch and a half beyond the red brick. But I was not able to follow it up properly and cannot give you any data, because the question is too difficult, as Mr. Bleininger says, and it was a very insignificant trial to make. But I believe if pottery companies will make up their minds to pay a little more for hollow fire brick and put up their kilns of them, it will be worth while.

Another question I wish to ask. In pointing out the loss of fuel in firing, in the beginning, Mr. Bleininger says that it is necessarily much greater than in a boiler. Is that your idea?

Mr. Bleininger: Yes, sir, not in the beginning so much as later on.

Mr. Langenbeck: I can understand that the greater the temperatures the greater the loss by radiation and gases might be, but your statement might be subject to the misinterpretation, as that a high temperature apparatus like a kiln is more wasteful in its work than a low temperature apparatus like a boiler. When we introduced gas at the Mosaic Tile Co., it proved more economical to fire our kilns with gas than with coal but not our boilers, and we returned to coal for firing the boilers. The kiln as an apparatus is much more economical of fuel, in my experience, measured by dollars and cents, than boilers, because the latter in its work chills the fire gases below the combustion temperature, the former does not.

Mr. Bleininger: I was referring to the effect produced. In the boiler you are getting effect measured by water evaporation; in the kiln, by the burning of the ware to a certain temperature. From this standpoint it is more economical than the kiln.

Mr. Langenbeck: I wanted to bring out what might be misinterpreted in that point.

Mr. Wheeler: We certainly are deeply indebted to Mr. Bleininger for this very valuable contribution, showing what we do not know. He has put a magnificent amount of work there, and the facts are very clearly and concisely stated.

I will ask one question to bring out one point more clearly. Were those kilns selected under normal conditions, with the common, everyday firing, or were they specially fired by expert workmen, and was there any handling of the kilns? I will also ask Mr. Bleininger, in that loss which he ascribes to radiation and kiln loss, whether he attempted to roughly differentiate between the external shell loss and what might be safely deducted as not external radiation? If he could give us a hint on that it would be greatly appreciated.

Mr. Bleininger: I have not attempted to do this. But in one case where the conditions were favorable, where the air was being drawn out of the kiln by a fan, we attempted to measure the heat retained in the kiln. We inserted a pyrometer and later on thermometers into the goose-neck, and knowing the pressure exerted by the fan we were able to roughly calculate the velocity. I have not finished the work, but we shall be able to calculate the weight of the air and the temperature, and therefore roughly the heat taken by the fan from the kiln. In other plants the conditions have not been favorable.

Answering the first question, I will say that the conditions were the ordinary conditions, no expert help being employed. I asked the superintendents to take no special precautions, but to let things go on in their usual way. Mr. Merry can tell us how he found conditions.

Mr. Merry: As to whether the kilns were the average or not, I think the sewer pipe kiln was the worst on the yard. The others were about the average kiln.

Mr. Aubrey: I will ask Mr. Bleininger what he calculates the heat retained by the ware? Is that heat taken to perform the mechanical action in the clay ware?

Mr. Bleininger: The calculated heat includes that

required for the expulsion of the mechanical water, the raising of the heat of the clay itself from the atmospheric temperature to the final temperature, and that taken by the expulsion of the chemical water. We have no accurate figures in regard to the heat of decomposition of the hydrous clay substances. I have assumed it to be 200 calories per gram of such water.